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Cenovus 10 MW CLC Field Pilot

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Abstract

It requires energy to extract bitumen from the vast Alberta oil sands resources, which results in greenhouse gas (GHG) emissions. Even though natural gas, the least carbon intensive fossil fuel is used to produce steam for bitumen recovery from *in situ* reserves, emissions of GHG continue to increase as the bitumen output is increasing annually. There is an urgent need to develop alternative lower CO_2 avoidance-cost carbon capture technologies, to mitigate these emissions. Chemical looping combustion (CLC) is an inherently CO_2 capture ready steam generation technology and has the potential of lower CO_2 avoidance cost. Cenovus Energy Inc. (Cenovus) engaged ANDRITZ Energy & Environment GmbH (AE&E) and Vienna University of Technology (TUV) to complete a preliminary design of a 10 MW CLC steam generator pilot (CLSG). It is designed to produce 16.5 tonnes per hour of 100 bar 100% quality steam using natural gas. Cenovus plans to install and operate it in its Christina Lake Thermal Project (Host). The Pilot will be completely integrated with the Host who will use the steam for oil production using Cenovus' steam assisted gravity drainage (SAGD) process. The successful demonstration of this Pilot will pave the way for design, construction and operation of commercial CLC boilers by 2020. This paper will discuss the CLSG designs, its development status, the test program to validate the performances of the 10 MW CLSG and the first generation NiO oxygen carrier.

Keywords: Cenovus; Christina Lake Thermal Project; Bitumen; SAGD; CLC; 10 MW; CLSG; Pilot

1. Introduction

In northeastern Alberta, there are about 293,000 million m^3 of bitumen resources contained in an area of 140,000 km^2. Of this in place bitumen, the estimated remaining reserves under active development [1] are about 27,000 million m^3. Bitumen is a low grade hydrocarbon of high density and viscosity, consisting of substantial amounts of impurities such as sulphur, nitrogen and metals. 80% of these reserves exist at least 200 m below ground and have to be extracted using enhanced recovery technologies

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due to its high viscosity in the reservoir. Cenovus is a pioneer and pace-setting producer using an enhanced recovery technology called steam assisted gravity drainage (SAGD)†.

The Canadian Association of Petroleum Producers' 2012 production forecast [2] estimated that thermal bitumen production would increase by about 9% per year from 135,000 m^3/d in 2011 to about 297,000 m^3/d in 2020. Even though natural gas, the least carbon intensive fossil fuel, is used in the steam generation, this production increase will result in substantial GHG emissions. Allowing for adoption of best practices in energy efficiency, the total GHG emissions from thermal production alone would be about 50 million tonnes per year in 2020, doubling the 2011 emissions. Cenovus has been a leader in applying new technologies in SAGD to reduce steam use and therefore GHG emissions. For examples, it has implemented insulated tubing, accelerated start up, patented Wedge Well™ technology, and solvent assisted process (SAP). As a result of this continuous innovation, Cenovus has the lowest energy and GHG intensities. Nevertheless, as production continues to grow, so will the growth of the total GHG emissions, even though each m^3 is produced with lower GHG emission. Therefore, in parallel with production R&D, Cenovus is researching alternatives to lower the high cost of post combustion carbon capture (PCC). To that end, it has undertaken research on its own and in collaboration with others in new carbon management technologies including chemical looping combustion (CLC).

Since 2008, Cenovus has collaborated with Vienna University of Technology (TUV) and ANDRITZ Energy & Environment GmbH (AE&E) in CLC. In 2009 a feasibility study was conducted to evaluate the CO_2 avoidance cost of a 300 MW‡ CLC vis-à-vis PCC using amine from conventional steam boilers for a nominal 6,000 m^3 per day SAGD production. The 300 MW CLC design was presented by Marx et al in INFUB9 in 2011 [3]. This feasibility study concluded that CLC has a CO_2 avoidance cost of about half that of PCC of conventional steam boilers when both are using natural gas. This result has been corroborated by others [4]. In order to ensure that CLC is a viable alternative by 2020, Cenovus has decided a 10 MW CLC steam generator (CLSG) pilot installed at its Christina Lake Thermal Project (Host) is the logical next step.

In the following sections we will report on the design of the 10 MW CLSG pilot, the preliminary project execution plan and the current status of the project.

2. Design of 10 MW Chemical Looping Steam Generator (CLSG)

Even though the largest CLC laboratory pilot is 120 kW in TUV using gaseous fuels, there is sufficient design and operating experiences in commercial circulating fluid bed (CFB) boilers and dual circulating fluidized bed (DCFB) (see Figure 1) reactors to scale it up by 80 times to a 10 MW CLSG pilot. After it is successfully demonstrated, it will pave our way quickly to 50 to 100 MW commercial units.

The background of DCFB development was well discussed previously [5]. It is ideally suitable for CLC as it provides intimate gas-particle contact and hence facilitates the reactions in both air and fuel reactors. Additionally it allows high global solids circulation rates and highly robust operation [6 & 7]. The lower loop seal provides an additional degree of operational freedom to control the solid circulation from the fuel reactor to the air reactor. Hence the fuel reactor cyclone can be relied on for the sole purpose of controlling particulate emission from the fuel reactor.

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† In SAGD, two horizontal wells are drilled into the bitumen reservoir where one well is placed 5 m above the other. High pressure steam is generated in simple once-through conventional boilers using natural gas and then injected in the top well of the pair. The steam rises and condenses in the reservoir to heat the bitumen to about 250 °C thereby lowering its viscosity by several orders of magnitude to about 10 mPa·s. The bitumen and steam condensate drain to the lower well and are produced to the surface where they are separated. The condensate is re-used in the boilers and bitumen is sold to refineries.

‡ All kW or MW in this paper refers to kW_{th} or MW_{th} in terms of lower heating value.

AE&E has extensive experience in the design and construction of both circulating and bubbling fluidized bed boilers for a variety of fuels. It has installed over 50 plants world wide, including several in North American, with steam outputs ranging from 30 to 500 tonnes per hour. It carried out the preliminary design of the 10 MW CLSG pilot using experiences from TUV's 120 kW CLC pilot and AE&E's CFB design principles. The design included commercially proven components while at the same time complexity was reduced to a level suitable for a pilot.

Due to the feed water quality in SAGD operations, additional considerations in the design of the pilot's steam generation equipment were necessary to avoid fouling and corrosion. Natural gas is a very clean fuel. However, the emission of micron-size particulate containing nickel compounds resulting from abraded oxygen carriers is the main concern due to nickel's health and safety issues.

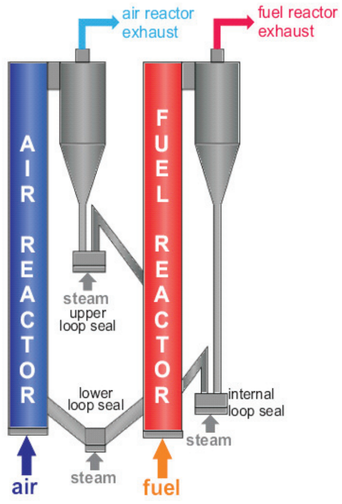

Figure 1: Dual circulating fluidized bed system for chemical looping applications.

Therefore, the pilot is designed to have complete emission monitoring and control systems to limit its particulate emissions to the EU limit of 0.5 mg of nickel per m^3 of flue gas. Each system consists of a primary cyclone, a secondary cyclone and a bag-house respectively for the air and fuel reactors. The remaining oxygen carrier handling system is modeled on the fly ash handling systems used in commercial CFB.

It was decided to use NiO oxygen carrier for the pilot, at least in the first year of operation. The primary reason to choose NiO is because there has been extensive research carried out in world wide laboratory pilots which provides a useful baseline reference for comparison with the prospective results of the 10 MW Pilot [8, 9 &10]. A secondary reason of its choice is that it has been successfully prepared in kg-batches. Consequently, the chance of scaling the preparation to tonne-batches would be possible. Its formulation is shown in Table 1. The design parameters of the CLSG are shown in Table 2.

Table 1: NiO oxygen carrier formulation

Parameter	Value	Unit
Mean particle diameter	140	μm
Particle density	3,400	Kg/m^3
Sphericity	0.95	-
Crushing strength	> 2	N
Attrition rate	TBD < FCC Catalyst	-
Composition		
NiO	40.6	%
$NiAl_2O_4$	50.7	
$MgAl_2O_4$	8.7	

Table 2: 10 MW reactor system basic design parameters

Parameter	Value	Unit
Fuel input (LHV)	10	MW
Design air/fuel ratio	1.05-1.40	-
Design fuel reactor temperature	850-950	°C
Design air reactor temperature	900-1000	°C
Design boiler feed water input	20	t/h
Design steam output (100 bar 100% quality)	16.5	t/h
Superficial gas velocity in the air reactor	7-8	m/s
Superficial gas velocity in the fuel reactor	5-6	m/s

3. Pilot Design Status and Execution Plan

Cenovus, working with AE&E and an Alberta engineering company, completed a pre-front end engineering design (pre-FEED) that resulted in the 10 MW CLSG design depicted in Figure 2 in a 3-D drawing without its structural support and boiler building.

As part of the pre-FEED work, the total cost of the Pilot was also estimated to be about $60 to 70 million. It includes the Pilot installation costs in the Host site at a Class IV level and two years of operation and maintenance costs. Cenovus has embarked on FEED in order to refine the designs respectively of (1) building structure, (2) steam generation and (3) equipment modularization, as well as installed cost estimate. The intent is to achieve a Class III level of installed cost estimate which is required in Cenovus' project approval by its management.

Modularization is a construction technique where equipment and piping are assembled in engineered steel frames in an assembly yard, which can then be transported to the Host's site and dropped into place.

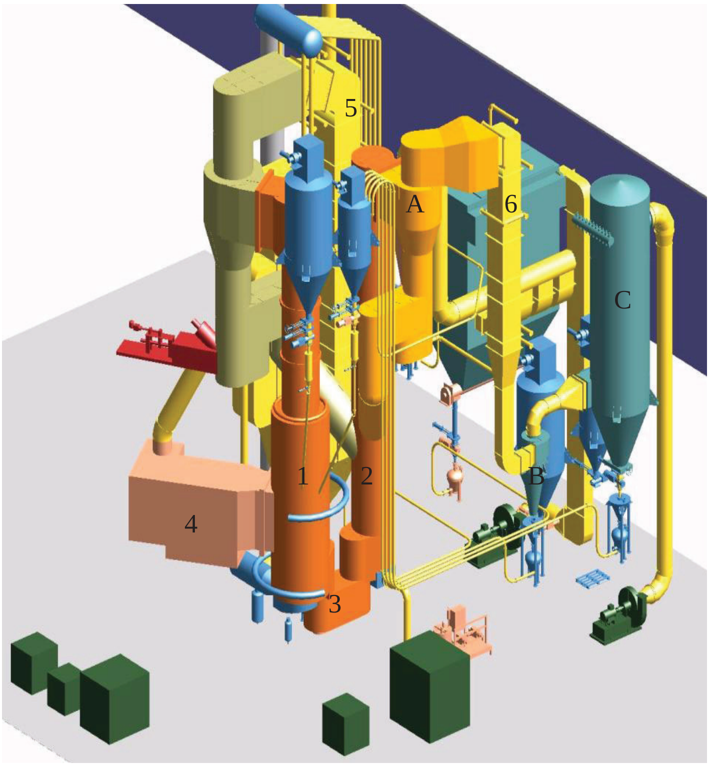

Figure 2: A 3-D drawing of the 10 MW CLSG pilot showing: (1) Air Reactor, (2) Fuel Reactor, (3) Lower Loop Seal, (4) Bed Material Cooler, (5) HRSG & (6) Economizer; and Fuel Reactor particulate control system (identical to that of the Air Reactor): (A) Primary cyclone, (B) Secondary Cyclone and (C) Bag-house.

This will reduce total installation costs and is already a Cenovus standard practice. Cenovus has entered an agreement with a US engineering company that has module fabrication yards in Texas and Montana. The CLSG reactor equipment will be manufactured in Europe and shipped to either one of these two module yards. These components will be incorporated into engineered steel modules in the yard. In western North America modules of 3.6 m × 3.6 m × 18.0 m can be transported on major highways with relative ease. The engineering process has to include modularization design and fabrication details as well as logistics early in FEED in order to complete the project successfully.

4. Plant location and tie-in

The Host is located in northeast Alberta. Figure 3 is a plot plan showing the prospective 10 MW CLSG Pilot locations (B or C) in relation to the Host's existing conventional boilers, and the tie-ins (shown in red) required to connect to existing steam distribution systems. The final location will be decided by the Host according to its operational plan and the availability of plot space.

Figure 4 is a preliminary schedule from 2012 to 2017 showing the major decision points and milestones, with the commissioning scheduled for the end of 2014 or the beginning of 2015.

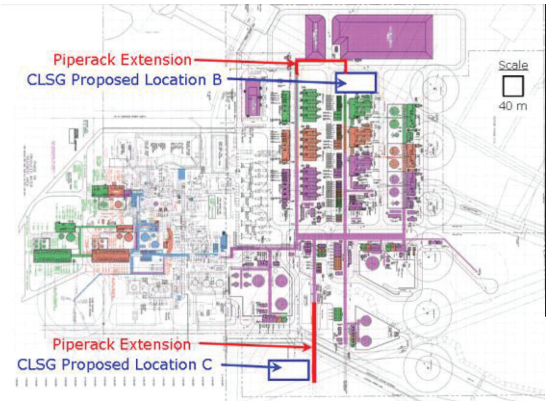

Figure 3: Host's Plot Plan showing prospective CLSG Pilot locations at B or C. Existing conventional boilers with their associated units are shown in green, orange and purple.

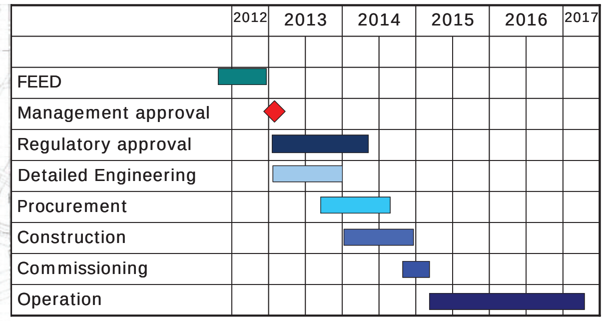

Figure 4: Preliminary schedule of the 10 MW CLSG

5. Preliminary Test program

The pilot is designed to produce 16.5 tonnes per hour of 100 bar 100% quality steam which will be added to Host's site steam supply for bitumen production. The pilot will operate for 2 calendar years from 2015 to 2017. Its test program will encompass three major components:

1. Learn to operate the pilot at steady state at the design parameters, and collect data for performance evaluation;
2. Conduct short campaigns to vary the design parameters including reactor temperature, solid circulation rate, and evaluate the pilot performance; and
3. Validate oxygen carrier performance pursuant to (1) and (2) above.

A detailed test program will be formulated after the detailed engineering is completed in 2014. If the test programs are successfully concluded in the first year, the goal of the second year will be to maximize steam output at the optimum operating conditions indicated by the test programs.

6. Project Financing

The biggest challenge of this project is to finance this pilot when the current carbon prices around the world are too low to incent carbon capture technology development. Therefore, Cenovus has decided that since this pilot will benefit everyone that employs fossil fuels for steam generation, it will lead the pilot project, and project financing should be shared by government, industry and Cenovus in approximately equal proportions. To that end, this three-way collaboration approach has been adopted. The prospective contributions from the Government of Alberta and Alberta Industry respectively are explained below.

Cenovus has applied to two Alberta agencies for financial support for this pilot. The first is the Innovative Energy Technology Program (IETP) administered by the Government of Alberta (www.energy.alberta.ca/OilSands/794.asp). The goal of IETP is to fund innovative resource recovery technologies that will also mitigate environmental footprints. The second is Alberta's Climate Change & Emission Management Corporation (CCEMC) (www.ccemc.ca). CCEMC is a non-profit corporation set up by the Government of Alberta to fund innovative GHG reduction technologies using money collected from Alberta large emitters under the authority of its Specified Gas Emission Regulation. On July 12th

2012, CCEMC announced its $10 million financial support of the Pilot starting with its detailed engineering design.

Cenovus has approached over 25 industry companies to solicit their financial support. Among them are the members of the Canada's Oil Sands Innovation Alliance Inc. (COSIA) (www.cosia.ca). COSIA was launched on March 1st 2012 when twelve Chief Executive Officers of the largest oil sands producers in Alberta pledged to accelerate the reduction of their environmental footprints in water, land, tailings and GHG. Cenovus has formulated a joint industry funding agreement that includes the terms for companies in and outside of COSIA that would offer financial support in return for design and operating information of, and new IP arising from, this Pilot.

7. Conclusions

As the GHG emissions of thermal bitumen production from Alberta oil sands continue to increase, carbon management technologies with low CO_2 avoidance cost are required so that the industry can afford to remove CO_2 from atmospheric emissions and safely store it underground. CLC appears to meet this low avoidance cost criterion. Therefore, Cenovus is planning to build and operate a 10 MW CLSG pilot at its Christina Lake Thermal Project to demonstrate this technology to advance it to commercial ready status by 2020. The technology team of AE&E, Cenovus and TUV is capable of designing, building and operating this pilot. Cenovus is also working diligently to secure adequate financing for this pilot through a three-way collaborative approach involving Cenovus, the Government of Alberta and industry companies

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